What is computer-generated imagery (CGI)?

Computer-generated imagery (CGI) is the creation of still or animated visual content using imaging software. CGI is used to produce images for many purposes, including visual art, advertising, anatomical modeling, architectural design, engineering, television (TV) shows, video game art and film special effects, as well as augmented reality (AR) and virtual reality (VR) applications.

CGI does not encompass traditional animation approaches like hand-drawn cartoons and frame-by-frame or stop-motion techniques, as those are not computer-generated. However, CGI is typically used in both live-action and animated films and often replaces traditional approaches. The term CGI encompasses everything from the use of algorithms for generating fractals -- or complex, never-ending visual patterns -- to computer programs that generate two-dimensional (2D) and three-dimensional (3D) animations and special effects.

How does CGI work?

In film and animation development, visual effects (VFX) departments oversee and create CGI using various methods. A primitive example of CGI is a 2D pixel-based image editor used to create shapes that make images. Today, VFX teams can use advanced computer software to create objects or characters that can be added seamlessly to existing real-life footage and even entire CGI scenes.

Complex visuals can also be created using other methods, such as combining computer-generated images into film in layers, a technique known as *compositing*. This technique is often used to place actors on a green screen in a simulated background.

Main use cases and examples of CGI

CGI software became an essential tool in the '90s and has been making advances since. Currently, multiple industries besides entertainment can utilize these software applications. Use cases include the following:

- **Film special effects.** CGI effects have become increasingly realistic and can accomplish things like adding elements to a background or environment -- such as weather conditions -- to modifying a character's physical appearance. An example is James Cameron's *Terminator 2*, which featured groundbreaking special effects, including liquid metal.

- **Video game graphics.** 3D computer graphics in video games use methods like rasterization, for example, which uses polygons -- typically triangles or quadrangles -- to model 3D objects. Rasterized 3D renders 3D scenes in real time and the results can be photorealistic with the precision of a photograph or nonphotorealistic.
- **Advertising.** Commercials and advertisements incorporate CGI to market products in compelling ways. The technology used to produce CGI is less expensive than it once was, and methods have become more efficient, so even smaller businesses can advertise their products with captivating imagery. In addition to video formats, still images can achieve similar results.
- **Architectural models.** In real-world scenarios, CGI specialists work with clients to produce 3D models of both interior and exterior spaces. These can be highly photorealistic and indicate how buildings will look, in clear detail, before construction begins.

History of CGI use

Various movies and TV shows over the last six decades exemplify the evolution of CGI and its capabilities. These include the following:

- **Vertigo.** The first time a basic example of CGI appeared onscreen was in 1958 after Alfred Hitchcock hired computer animation pioneer John Whitney to create the opening sequence in *Vertigo*.
- **Tron.** In the early '80s, *Tron* introduced a groundbreaking combination of live-action and CGI imagery. While it wasn't the first film in history to use CGI, it was the most extensive use of CGI at the time of its release.
- **Jurassic Park.** Science fiction and action films like *Jurassic Park* are notable for using CGI technology that was considered advanced in 1993. Even though computer-generated images were used sparingly throughout the movie, they were highly impactful, leaving a lasting impression in viewers' minds.

- **Toy Story.** This Disney-Pixar collaboration was made entirely with CGI and is arguably considered the first film to have achieved this feat. Pixar followed this format with subsequent films, including *Monsters, Inc.* and *Finding Nemo*.
- **Titanic.** *Titanic* used a combination of CGI and practical effects for parts where the ship's exterior was in focus. This film's use of CGI was considered modern in the late '90s but is now outdated by 21st century standards.
- **Lord of the Rings.** This trilogy featured characters, creatures and parts of battle scenes based entirely on CGI. However, practical effects were mainly used, with CGI only being used when there was no realistic alternative.

DEVRIMB/GETTY IMAGES
Today's CGI software offers 3D modeling and texturing capabilities to create immersive characters, creatures or backgrounds.

Future of CGI

New technologies will play an increasing role in various industries in the future, with entertainment being no exception. Burgeoning tech like machine learning, a subset of AI, can make the process of producing CGI more efficient once this technology becomes more ubiquitous and hence less expensive.

Both AI and CGI have advanced rapidly, at a pace few could have foreseen many years ago. Therefore, it's too speculative to predict how big of a role AI will play within CGI. However, it's unlikely that such technology will replace CGI artists -- at least in the foreseeable future.

In addition, other related technologies that have been subject to hype could potentially make their way into the realm of CGI. For example, despite the notoriety of deepfake AI technology, deepfakes can be used for more realistic VFX as well.

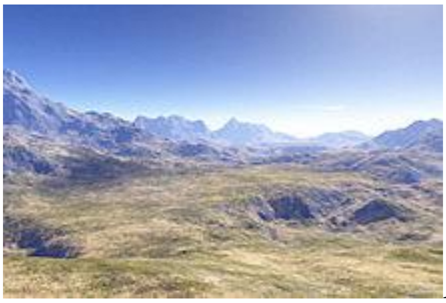
Also, VR could revolutionize computer and video game design as it becomes more immersive and better developed over time.

As the tech sector intensifies its focus on AR and VR, it's important to know how these two technologies compare and how they differ from what some call "mixed reality."

APPLICATIONS:

Static images and landscapes[edit]

See also: Fractal landscape and Scenery generator



A fractal landscape created in Terragen

Not only do animated images form part of computer-generated imagery; natural looking landscapes (such as fractal landscapes) are also generated via computer algorithms. A simple way to generate fractal surfaces is to use an extension of the triangular mesh method, relying on the construction of some special case of a de Rham curve, e.g., midpoint displacement.[10] For instance, the algorithm may start with a large triangle, then recursively zoom in by dividing it into four smaller Sierpinski triangles, then interpolate the height of each point from its nearest neighbors.[10] The creation of a Brownian surface may be achieved not only by adding noise as new nodes are created but by adding additional noise at multiple levels of the mesh.[10] Thus a topographical map with varying levels of height can be created using relatively straightforward fractal algorithms. Some typical, easy-to-program fractals used in CGI are the *plasma fractal* and the more dramatic *fault fractal*.[11]

Many specific techniques have been researched and developed to produce highly focused computer-generated effects — e.g., the use of specific models to represent the chemical weathering of stones to model erosion and produce an "aged appearance" for a given stone-based surface.[12]

Architectural scenes

A computer-generated image featuring a house at sunset, made in Blender

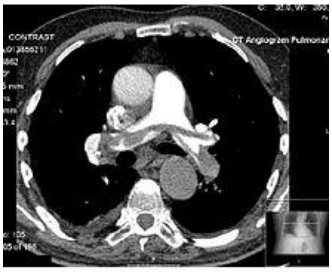
Modern architects use services from computer graphic firms to create 3-dimensional models for both customers and builders. These computer generated models can be more accurate than traditional drawings. Architectural animation (which provides animated movies of buildings, rather than interactive images) can also be used to see the possible relationship a building will have in relation to the environment and its surrounding buildings. The processing of architectural spaces without the use of paper and pencil tools is now a widely accepted practice with a number of computer-assisted architectural design systems.[13]

Architectural modeling tools allow an architect to visualize a space and perform "walk-throughs" in an interactive manner, thus providing "interactive environments" both at the urban and building levels.[14] Specific applications in architecture not only include the specification of building structures (such as walls and windows) and walk-throughs but the effects of light and how sunlight will affect a specific design at different times of the day.[15][16]

Architectural modeling tools have now become increasingly internet-based. However, the quality of internet-based systems still lags behind sophisticated in-house modeling systems.[17]

In some applications, computer-generated images are used to "reverse engineer" historical buildings. For instance, a computer-generated reconstruction of the monastery at Georgenthal in Germany was derived from the ruins of the monastery, yet provides the viewer with a "look and feel" of what the building would have looked like in its day.[18]

Anatomical models



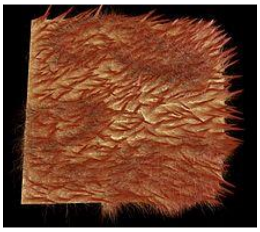
A CT pulmonary angiogram image generated by a computer from a collection of x-rays

Computer generated models used in skeletal animation are not always anatomically correct. However, organizations such as the Scientific Computing and Imaging Institute have developed anatomically correct computer-based models. Computer generated anatomical models can be used both for instructional and operational purposes. To date, a large body of artist produced medical images continue to be used by medical students, such as images by Frank H. Netter, e.g. Cardiac images. However, a number of online anatomical models are becoming available.

A single patient X-ray is not a computer generated image, even if digitized. However, in applications which involve CT scans a three-dimensional model is automatically produced from many single-slice x-rays, producing "computer generated image". Applications involving magnetic resonance imaging also bring together a number of "snapshots" (in this case via magnetic pulses) to produce a composite, internal image.

In modern medical applications, patient-specific models are constructed in 'computer assisted surgery'. For instance, in total knee replacement, the construction of a detailed patient-specific model can be used to carefully plan the surgery.[19] These three-dimensional models are usually extracted from multiple CT scans of the appropriate parts of the patient's own anatomy. Such models can also be used for planning aortic valve implantations, one of the common procedures for treating heart disease. Given that the shape, diameter, and position of the coronary openings can vary greatly from patient to patient, the extraction (from CT scans) of a model that closely resembles a patient's valve anatomy can be highly beneficial in planning the procedure.[20]

Cloth and skin images


Computer-generated wet fur created in Autodesk Maya

Models of cloth generally fall into three groups:

- The geometric-mechanical structure at yarn crossing
- The mechanics of continuous elastic sheets
- The geometric macroscopic features of cloth.[21]

To date, making the clothing of a digital character automatically fold in a natural way remains a challenge for many animators.[22]

In addition to their use in film, advertising and other modes of public display, computer generated images of clothing are now routinely used by top fashion design firms.[23]

The challenge in rendering human skin images involves three levels of realism:

- **Photo realism** in resembling real skin at the static level
- **Physical realism** in resembling its movements
- **Function realism** in resembling its response to actions.[24]

The finest visible features such as fine wrinkles and skin pores are the size of about 100 µm or 0.1 millimetres. Skin can be modeled as a 7-dimensional bidirectional texture function (BTF) or a collection of bidirectional scattering distribution function (BSDF) over the target's surfaces.

Interactive simulation and visualization

Interactive visualization is the rendering of data that may vary dynamically and allowing a user to view the data from multiple perspectives. The applications areas may vary significantly, ranging from the visualization of the flow patterns in fluid dynamics to specific computer aided design applications.[25] The data rendered may correspond to specific visual scenes that change as the user interacts with the system — e.g. simulators, such as flight simulators, make extensive use of CGI techniques for representing the world.[26]

At the abstract level, an interactive visualization process involves a "data pipeline" in which the raw data is managed and filtered to a form that makes it suitable for rendering. This is often called the **"visualization data"**. The visualization data is then mapped to a "visualization representation" that can be fed to a rendering system. This is usually called a **"renderable representation"**. This representation is then rendered as a displayable image.[26] As the user interacts with the system (e.g. by using joystick controls to change their position within the virtual world) the raw data is fed through the pipeline to create a new rendered image, often making real-time computational efficiency a key consideration in such applications.[26][27]

Computer animation

While computer-generated images of landscapes may be static, *computer animation* only applies to dynamic images that resemble a movie. However, in general, the term computer animation refers to dynamic images that do not allow user interaction, and the term virtual world is used for the interactive animated environments.

Computer animation is essentially a digital successor to the art of stop motion animation of 3D models and frame-by-frame animation of 2D illustrations. Computer generated animations are more controllable than other more physically based processes, such as constructing miniatures for effects shots or hiring extras for crowd scenes, and because it allows the creation of images that would not be feasible using any other technology. It can also allow a single graphic artist to produce such content without the use of actors, expensive set pieces, or props.

To create the illusion of movement, an image is displayed on the computer screen and repeatedly replaced by a new image which is similar to the previous image, but advanced slightly in the time domain (usually at a rate of 24 or 30 frames/second). This technique is identical to how the illusion of movement is achieved with television and motion pictures.

Text-to-image models

An image conditioned on the prompt "an astronaut riding a horse, by Hiroshige", generated by Stable Diffusion, a large-scale text-to-image model released in 2022

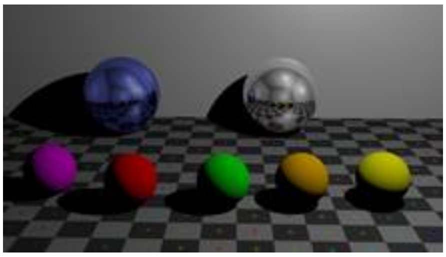
A text-to-image model is a machine learning model which takes an input natural language description and produces an image matching that description.

Such models began to be developed in the mid-2010s during the beginnings of the AI spring, as a result of advances in deep neural networks. In 2022, the output of state of the art text-to-image models, such as OpenAI's DALL-E 2, Google Brain's Imagen, StabilityAI's Stable Diffusion, and Midjourney began to approach the quality of real photographs and human-drawn art.[citation needed]

Text-to-image models generally combine a language model, which transforms the input text into a latent representation, and a generative image model, which produces an image conditioned on that representation. The most effective models have generally been trained on massive amounts of image and text data scraped from the web.[28]

Virtual worlds

A yellow submarine in *Second Life*



Metallic balls created in Blender

A virtual world is an agent-based and simulated environment allowing users to interact with artificially animated characters (e.g software agent) or with other physical users, through the use of avatars. Virtual worlds are intended for its users to inhabit and interact, and the term today has become largely synonymous with interactive 3D virtual environments, where the users take the form of avatars visible to others graphically.[29] These avatars are usually depicted as textual, two-dimensional, or three-dimensional graphical representations, although other forms are possible[30] (auditory[31] and touch sensations for example). Some, but not all, virtual worlds allow for multiple users.

In courtrooms

Computer-generated imagery has been used in courtrooms, primarily since the early 2000s. However, some experts have argued that it is prejudicial. They are used to help judges or the jury to better visualize the sequence of events, evidence or hypothesis.[32] However, a 1997 study showed that people are poor intuitive physicists and easily influenced by computer generated images.[33] Thus it is important that jurors and other legal decision-makers be made aware that such exhibits are merely a representation of one potential sequence of events.

Broadcast and live events

Weather visualizations were the first application of CGI in television. It has now become common in weather casting to display full motion video of images captured in real-time from multiple cameras and other imaging devices. Coupled with 3D graphics symbols and mapped to a common virtual geospatial model, these animated visualizations constitute the first true application of CGI to TV.

CGI has become common in sports telecasting. Sports and entertainment venues are provided with see-through and overlay content through tracked camera feeds for enhanced viewing by the audience. Examples include the yellow "first down" line seen in television broadcasts of American football games showing the line the offensive team must cross to receive a first down. CGI is also used in association with football and other sporting events to show commercial advertisements overlaid onto the view of the playing area. Sections of rugby fields and cricket pitches also display sponsored images. Swimming telecasts often add a line across the lanes to indicate the position of the current record holder as a race proceeds to allow viewers to compare the current race to the best performance. Other examples include hockey puck tracking and annotations of racing car performance[34] and snooker ball trajectories.[35][36] Sometimes CGI on TV with correct alignment to the real world has been referred to as augmented reality.

Motion-capture

Computer-generated imagery is often used in conjunction with motion-capture to better cover the faults that come with CGI and animation. Computer-generated imagery is limited in its practical application by how realistic it can look. Unrealistic, or badly managed computer-generated imagery can result in the Uncanny Valley effect.[37] This effect refers to the human ability to recognize things that look eerily like humans, but are slightly off. Such ability is a fault with normal computer-generated imagery which, due to the complex anatomy of the human-body, can often fail to replicate it perfectly. This is where motion-capture comes into play. Artists can use a motion-capture rig to get footage of a human performing an action and then replicate it perfectly with computer-generated imagery so that it looks normal.

The lack of anatomically correct digital models contributes to the necessity of motion-capture as it is used with computer-generated imagery. Because computer-generated imagery reflects only the outside, or skin, of the object being rendered, it fails to capture the infinitesimally small interactions between interlocking muscle groups used in fine motor-control, like speaking. The constant motion of the face as it makes sounds with shaped lips and tongue movement, along with the facial expressions that go along with speaking are difficult to replicate by hand.[38] Motion capture can catch the underlying movement of facial muscles and better replicate the visual that goes along with the audio, like Josh Brolin's Thanos.